Effect of a Carbohydrate-Electrolyte Beverage, Lemon Tea, or Water on Rehydration During Short-Term Recovery From Exercise

Stephen Heung-Sang Wong and Yajun Chen

**Purpose:** This study examined the rehydration achieved by drinking different beverages during a short-term recovery period (REC) after exercise-induced dehydration. **Methods:** Thirteen well-trained men (age 22.1 ± 3.3 yr, body mass 61.2 ± 9.1 kg, $V_{O2\text{max}}$ 64.9 ± 4.0 ml · kg$^{-1}$ · min$^{-1}$, maximum heart rate 198 ± 7 beats/min) ran for 60 min on 3 occasions on a level treadmill at 70% $V_{O2\text{max}}$. All trials were performed in thermoneutral conditions (21 °C, 71% relative humidity) and were separated by at least 7 d. During 4 hr REC, the subjects consumed either a volume of a carbohydrate-electrolyte beverage (CE), lemon tea (LT), or distilled water (DW) equal to 150% of the body weight (BW) lost during the previous run. The fluid was consumed in 6 equal volumes at 30, 60, 90, 120, 150, and 180 min of REC. **Results:** After the completion of the 60-min run, the subjects lost ~2.0% of their preexercise BW in all trials, and no differences were observed in these BW changes between trials. At the end of REC, the greatest fraction of the retained drink occurred when the CE drink was consumed (CE vs. LT vs. DW: 52% ± 18% vs. 36% ± 15% vs. 30% ± 14%, $p < .05$). The CE drink also caused the least diuretic effect (CE vs. LT vs. DW: 638 ± 259 vs. 921 ± 323 vs. 915 ± 210 ml, $p < .05$) and produced the optimal restoration of plasma volume (CE vs. LT vs. DW: 11.2% ± 2.0% vs. –3.1% ± 1.8% vs. 0.2% ± 2.1%, $p < .05$). **Conclusion:** The results of this study suggest that CE drinks are more effective than DW or LT in restoring fluid balance during short-term REC after exercise-induced dehydration.

**Keywords:** sports drink, rehydration, run

Heavy sweating during prolonged submaximal exercise can cause body-fluid losses in excess of 1 L/hr (Costill, 1977). The resultant dehydration will inevitably lead to fatigue (American College of Sports Medicine [ACSM] et al., 2007; Ray et al., 1998). Rapid rehydration after exercise is important for optimal cardiovascular function and thermoregulation during subsequent bouts of exercise (Maughan, Leiper, & Shirreffs, 1996; Montain & Coyle, 1992; Shirreffs & Maughan, 1998; Wong & Williams, 2000; Wong, Williams, & Adams, 2000). Dehydration does not delay muscle glycogen resynthesis (Neufer et al., 1991) but may be responsible for an inability to recover completely from prolonged exercise (Maughan et al., 1996).

Replacing water and electrolytes during rehydration can be limited by gastric emptying and intestinal absorption, as well as the body’s ability to retain ingested fluids (Gisolfi, Summers, Schedl, Bleiler, & Oppliger, 1990; Mitchell & Voss, 1991). The mechanisms by which specific components of drinks confer advanced hydration have been extensively studied. Plain water ingestion after exercise results in a fall in plasma osmolality and sodium concentration, which stimulates urine production and reduces the drive to drink (Nose, Mack, Shi, & Nadel, 1988) and in turn delays the rehydration process. In contrast, adding sodium chloride to plain water increases fluid intake while reducing urine output (Nose et al., 1988). However, high sodium content can make a drink unpalatable (Nose et al., 1988; Wemple, Lamb, & McKeever, 1997).

Although optimal fluid balance is important for athletes after exercise, other factors such as palatability often dictate the choice of beverage in day-to-day situations, because both psychological and physiological factors govern intake (Passe, Horn, Stofan, Murray, 2004). Commercially available sports drinks appear to meet a balance between efficacy and palatability and typically contain 10–30 mmol/l of sodium. Carbohydrate-based sports beverages are sometimes used to meet carbohydrate needs while attempting to replace sweat water and electrolyte losses (Murray, Bartoli, Stofan, Horn, & Eddy, 1999). Taken in combination with their enhanced palatability (Passe et al., 2004), they might provide a distinct advantage in terms of rehydration over plain water.

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The benefits of, and the physiological responses associated with, fluid replacement before and during exercise (Armstrong, Costill, & Fink, 1985; Coyle, 2004; Kavouras, 2002; Kavouras et al., 2006; Mitchell et al., 1988; Ryan, Bleiler, Carter, & Gisolfi, 1989) have been extensively studied. However, relatively little research has been undertaken to investigate fluid replenishment during the short-term postexercise recovery period (REC; 4 hr) despite the fact that the optimum physiological function of cells depends on the constancy of their fluid balance (Wong & Williams, 2000; Wong et al., 2000).

Rapid recovery from exercise-induced dehydration is essential in all situations, but especially in very hot environmental conditions such as those experienced in Hong Kong for much of the year. Despite the effectiveness of various beverage formulations to replace fluids and minerals lost through sweat in many scientific reports, people show a preference for drinks they have traditionally had (Saat, Singh, Sirisinghe, & Nawawi, 2002; Shirreffs, Aragon-Vargas, Keil, Love, & Phillips, 2007). These choices might reflect cultural preference, availability, cost, or the influence of beverage industry advertising. A recent survey on the dietary behavior among Chinese adults in Hong Kong showed that lemon tea with water (41%) was the most commonly consumed acidic beverage in 520 participants interviewed (Chu, Pang, & Lo, 2010). Different kinds of commercially available sport drinks or soft drinks have been promoted locally for fluid replacement during and after physical activities. The efficacy of these drinks is rarely questioned and investigated. Unwarranted claims about such drinks are frequently advertised, but because of the dearth of research, guidelines for selecting the most appropriate fluids (including those for traditionally local drinks) after exercise are not available to the public.

Therefore, the purpose of this study was to examine the effectiveness of three beverages typically consumed in Hong Kong after exercise—lemon tea (LT), distilled water (DW), and a carbohydrate-electrolyte beverage (CE)—on whole-body rehydration after exercise-induced dehydration.

**Methods**

**Subjects**

Thirteen well-trained male runners volunteered for this study, which was approved by the university ethical committee. The subjects were all nonsmokers and their mean (± SD) age, body weight (BW), maximal oxygen uptake (VO2max), and maximum heart rate (HR) were 22.1 ± 3.3 years, 61.2 ± 9.1 kg, 64.9 ± 4.0 ml · kg⁻¹ · min⁻¹, and 198 ± 7 beats/min, respectively. Before their involvement in the study, subjects completed a medical-history questionnaire and provided general details of their training background and running ability. The nature of the study and all its experimental procedures were explained in written and verbal form, and the subjects then signed a written consent indicating their understanding of the study’s requirements.

**Preliminary Measurements**

Before the three main trials, all subjects were briefed about running on a treadmill (LE 500 C, Jaeger, Germany) and completed three preliminary tests. In the first, a 16-min incremental, submaximal running test was used to determine the relationship between running speed and VO2. VO2max was then determined during uphill, incremental treadmill running to volitional exhaustion, as described elsewhere (Williams, Nute, Broadbank, & Vinall, 1990). Using the results obtained from these two tests, the running speed required to elicit 70% of each subject’s VO2max was calculated. That this calculated running speed elicited the appropriate exercise intensity was verified 1 week before the first main trial during a 30-min treadmill run. During this run, the subjects were fully briefed on all procedures and measurements employed during the main trials. To avoid any unwitting modification of diet before the main trials, subjects were asked to complete a food intake diary 3 days before their first main trial. This diet was then replicated 3 days before the remaining two trials. In all tests and trials, expired-air samples were collected using the Douglas-bag method. During the first testing session, subjects had their height measured using a wall-mounted stadiometer (Holstain Ltd., Britain). Before each preliminary session, with the subject clad in shorts only, BW was established to the nearest 100 g using an electronic digital balance scale (Model BWB 600, Tanita, Japan).

**Experimental Protocol**

During the main trials, the effectiveness of a CE beverage, LT, or DW for promoting rehydration after exercise-induced dehydration was examined. All main trials were conducted in the exercise physiology laboratory at the Chinese University of Hong Kong under similar environmental conditions (dry-bulb temperature 21 °C, relative humidity 71%). The three main trials were separated by at least 7 days. The subjects reported to the laboratory on the morning of a main trial after an overnight (10–12 hr) fast. Before going to bed, they consumed 500 ml of water to ensure euhydration the following morning. On arrival at the laboratory, the subjects voided, were weighed nude, and sat quietly for 30 min. After standing for 20 min, a venous blood sample was obtained without stasis. This blood sample represented the euhydrated state and was analyzed for hemoglobin, hematocrit, plasma osmolality, and plasma electrolytes (Na⁺ and K⁺). The subjects then ran on the treadmill at 70% VO2max for 60 min.

During the 60-min run, capillary blood samples, expired-air samples, and the ratings of perceived exertion (Borg, 1982) were collected at 15-min intervals. A
short-range radio telemeter (Sport Tester PE 4000, Polar Electro, Finland) was used to monitor the HR of subjects continuously throughout the main trials. Immediately after the run, the 4-hr rehydration REC commenced. On completing the run, subjects were allowed to cool down sufficiently until they stopped sweating. They then towel-dried and their nude BW was determined; this represented their dehydrated level. Subjects then put on a shirt and shorts and sat while a Teflon venous cannula was placed in a forearm vein. Venous blood samples and expired-air samples were obtained at 1-hr intervals during the REC. Capillary blood samples were collected and aural temperature was measured at 30-min intervals during the REC (ThermoTek, Swire Loxley Ltd., Hong Kong).

During the REC, subjects drank either a CE beverage (Pocari Sweat, Otsuka Pharmaceutical Co., Ltd.: 109 kJ/100 ml, CHO 6.6%, Na⁺ 21 mEq/L), sweetened LT (Hong Kong: 202 kJ/100 ml, CHO 12%, Na⁺ 5 mEq/L), or DW (Watsons, Hong Kong). The total intake of fluid during REC was equivalent to 150% of BW lost (ACSM et al., 2007) during the 60-min run. The fluid was consumed in six equal volumes at 30, 60, 90, 120, 150, and 180 min of REC. The temperature of the beverages was 10–15 °C. Throughout REC, the volume of urine produced by subjects was measured. At 30, 60, 90, 120, 150, 180, 210, and 240 min of the REC, subjects were asked about their sensations of thirst, abdominal discomfort, and stomach fullness. Their answers were scaled from 1 to 10, where 1 was not so much and 10 was very much. At the end of the REC, nude BW was determined. The percentage of BW loss regained was used as an index of whole-body rehydration (percent rehydration).

**Blood Analysis**

All blood samples (5 ml) were drawn from an antecubital vein after subjects stood for 20 min. Each blood sample was placed in a plastic test tube for analysis of the osmolality and for later centrifugation and separation of plasma, which was analyzed for plasma Na⁺ and K⁺ concentrations. Blood glucose concentrations were determined immediately by the patented immobilized enzyme technology using a glucose analyzer (Model 1500 Sidekick, YSI, Ohio). Hemoglobin (Hb) concentration was determined using the cyanmethemoglobin technique (Bayer Diagnostics, RA-50 Chemistry Analyzer, Germany). Hematocrit of the whole blood was determined with duplicate samples in a hematocrit reader (Clay Adams, Autocrit Ultra 3, USA) after microcentrifugation. Percentage changes in plasma volume were calculated from changes in Hb and hematocrit. The plasma osmolality was determined in duplicate by the hygrometric method of a vapor pressure osmometer (Model 5520, Wescor, UT). The sodium and potassium concentrations were measured in duplicate by a direct potentiometric analyzer (614 Na⁺/K⁺ Analyzer, Ciron Diagnostics, Essex, UK).

**Statistical Analysis**

Comparison of the subjects’ responses resulting from the consumption of the three beverages was made using a two-way analysis of variance (Trial × Time) with repeated measures. Significant differences were located using Turkey’s post hoc analysis. If a data set was not normally distributed, statistical analysis would be performed on the logarithmic transformation of the data. Assumptions of homogeneity and sphericity in the data were checked, and an adjustment in the degrees of freedom for the ANOVA would be made when necessary. All data were presented as $M \pm SD$, with the significance set at $p < .05$. The effect size was also estimated for the strength of meaningfulness of the treatment effects.

**Results**

The average percentage $\text{VO}_{2\text{max}}$ values sustained during the 60-min run in the CE, LT, and DW trials were 70.2% ± 1.1%, 70.1% ± 1.4%, and 70.0% ± 0.7%, respectively (NS). After the completion of the 60-min run, the subjects lost ~2.0% of their preexercise BW in all trials, and no differences were observed in these BW changes between trials (CE vs. LT vs. DW: 2.0% ± 0.3% vs. 2.1% ± 0.3% vs. 2.1% ± 0.3%). Accordingly, the total volumes of fluid prescribed were 1,869 ± 355, 1,890 ± 373, and 1,951 ± 327 ml for the CE, LT, and the DW trials, respectively. By the end of REC, subjects retained 52% ± 18% (970 ± 360 ml), 36% ± 15% (680 ± 280 ml), and 30% ± 14% (600 ± 270 ml) of the volume ingested in the CE, LT, and DW trials, respectively. Similarly, the 2% BW fluid losses, 77.4% ± 19.6% were replaced when the CE solution was ingested during the 4-hr REC. This is high compared with 53.7% ± 23.4% with the LT ($p < .05$ vs. other drinks) and 45.5% ± 15.7% when DW was consumed ($p < .05$ vs. other drinks; Figure 1).

Regarding cumulative urine output during REC, the CE solution caused the least diuretic effect of the beverages (CE vs. LT vs. DW: 638 ± 259 vs. 921 ± 323 vs. 915 ± 210 ml, $p < .05$). When subjects consumed LT and DW, the urine output peaked at the third hour of the REC, whereas urine production primarily occurred at the last hour when subjects drank the CE solution (Figure 2). The total volumes of urine represented ~34%, ~49%, and ~47% of fluid ingested during the CE, LT, and DW trials, respectively.

Figure 3 shows the changes in plasma volume resulting from exercise-induced dehydration in the 60-min run and during REC. All values are expressed as a percentage change from the resting levels. Plasma volume decreased approximately 10% after the 60-min run on each occasion. When subjects drank LT, their plasma volume at the end of REC still tended to be lower than the preexercise level (1 hr, −0.6% ± 2.3%; 2 hr, −0.2% ± 2.3%; 3 hr, −1.1% ± 2.1%; 4 hr, −3.1% ± 1.8%; NS). The percentage of plasma volume change was higher
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Figure 1 — Fate of ingested volume during recovery for carbohydrate-electrolyte beverage (CE), lemon tea (LT), and distilled water (DW). The height of the graph represents the total amount of fluid consumed. *CE vs. LT vs. DW, \( p < .05 \).

After the REC when subjects ingested the CE solution (CE vs. LT vs. DW: 11.2% ± 2.0% vs. -3.1% ± 1.8% vs. 0.2% ± 2.1%, \( p < .05 \)).

Plasma osmolality increased after the 60-min run in all trials, but no differences were found between treatments (Figure 4). When subjects drank the LT, their plasma osmolality remained elevated during REC and almost returned to the preexercise value at the end of REC compared with the CE solution and DW (CE vs. LT vs. DW: 272 ± 12 vs. 280 ± 10 vs. 268 ± 10 mOsm/kg, \( p < .05 \)). The values were similar between the CE and DW trials at all time points during REC.

During the 60-min run, blood glucose concentrations were equally well maintained within the normal range in all trials (Figure 5). Glucose concentration then increased to the highest level (7.0 ± 1.1 mmol/L) in the LT trial by the first hour during REC (\( p < .05 \)), and it remained elevated throughout the REC. When subjects drank the CE solution during REC, similar blood glucose responses were observed, but the blood glucose concentration eventually returned to 4.4 ± 1.1 mmol/L at the end of REC. When continually ingesting DW, the glucose concentration remained unchanged during REC.

All trials demonstrated an increase in serum Na⁺ concentration during the 60-min run (\( p < .05 \)) but it decreased during the REC in the DW trial (\( p < .05 \)). The value dropped to 140 ± 1 at the end of REC (Figure 6). However, the values were greater (\( p < .05 \)) after the second hour of REC when the CE solution and the LT beverage were ingested. No differences were observed between CE and LT trials at the end of REC (CE vs. LT:
Figure 2 — Accumulated urine volume during the recovery in the carbohydrate-electrolyte beverage (CE), lemon tea (LT), and distilled water (DW) trials. \( p < .05 \), CE vs. LT. \( p < .05 \), CE vs. DW.

Figure 3 — Change of plasma volume (PV) before and after the 60-min run and during recovery in the carbohydrate-electrolyte beverage (CE), lemon tea (LT), and distilled water (DW) trials. \( p < .05 \), CE vs. LT. \( p < .05 \), CE vs. DW.
Figure 4 — Change in plasma osmolality before and after the 60-min run and during recovery in the carbohydrate-electrolyte beverage (CE), lemon tea (LT), and distilled water (DW) trials. $^a p < .05$, CE vs. LT. $^b p < .05$, LT vs. DW.

Figure 5 — Change in glucose concentration during recovery in the carbohydrate-electrolyte beverage (CE), lemon tea (LT), and distilled water (DW) trials. $^a p < .05$, CE vs. LT. $^b p < .05$, CE vs. DW. $^c p < .05$, LT vs. DW.
There were no differences in the serum K\textsuperscript+ concentrations between trials at any time point.

The aural temperature was similarly regulated in all trials during exercise and REC, and no differences were found between treatments. Exercising HR rose progressively during the run in all conditions (Table 1). Although the values tended to be higher at the end of REC in the LT trial, this did not reach statistical significance because of large individual variability. During the run, no differences were found in the respiratory-exchange ratio among trials. However, the respiratory-exchange ratios in both LT and CE trials were greater than that in the DW trial during the entire REC ($p < .05$), although there were no differences between the LT and CE trials (Table 1).

There were no differences in the ratings of perceived exertion during the run and the REC in all conditions (Table 1). Ratings of abdominal discomfort were lower in the last 2 hr in REC in the CE and DW trials, but no differences were observed at any other time point in the experimental conditions (Table 2). Furthermore, subjects reported higher stomach fullness, and some reported feeling bloated when drinking the LT solution in the 4-hr REC (Table 2). With respect to perceived thirst during the trials, a consistent increase in the sensation of thirst was experienced by all subjects throughout the run. However, there were no differences because of the experimental treatments.

**Discussion**

The main finding in this study is that the degree of rehydration produced after exercise was greatest when a CE solution was ingested compared with LT or DW. Of the 2% BW fluid losses induced by the 60-min run, 77.4%, on average, were replaced when the CE solution was consumed, which is high compared with 53.7% with LT ($p < .05$ vs. other drinks) and 45.5% when DW was consumed ($p < .05$ vs. other drinks). Consumption of the CE solution also produced the least diuretic effect among the consumed beverages, with urine losses...
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Table 1 Heart Rate (HR), Ratings of Perceived Exertion (RPE), and Respiratory Exchange Ratio (RER) During Exercise and Recovery in the Carbohydrate-Electrolyte Beverage (CE), Lemon Tea (LT), and Distilled Water (DW) Trials (*M ± SD*)

<table>
<thead>
<tr>
<th></th>
<th>Exercise Period (min)</th>
<th>Recovery Period (min)</th>
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<tr>
<td></td>
<td>15</td>
<td>30</td>
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<tr>
<td><strong>HR</strong></td>
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<tr>
<td>CE</td>
<td>160 ± 14</td>
<td>163 ± 22</td>
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<tr>
<td>LT</td>
<td>160 ± 14</td>
<td>165 ± 29</td>
</tr>
<tr>
<td>DW</td>
<td>160 ± 18</td>
<td>164 ± 22</td>
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<tr>
<td><strong>RPE</strong></td>
<td></td>
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<tr>
<td>CE</td>
<td>9 ± 2</td>
<td>10 ± 2</td>
</tr>
<tr>
<td>LT</td>
<td>10 ± 2</td>
<td>12 ± 2</td>
</tr>
<tr>
<td>DW</td>
<td>9 ± 2</td>
<td>12 ± 3</td>
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<tr>
<td><strong>RER</strong></td>
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<tr>
<td>CE</td>
<td>0.89 ± 0.25</td>
<td>0.89 ± 0.24</td>
</tr>
<tr>
<td>LT</td>
<td>0.90 ± 0.27</td>
<td>0.89 ± 0.34</td>
</tr>
<tr>
<td>DW</td>
<td>0.90 ± 0.29</td>
<td>0.89 ± 0.31</td>
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*a* *p < .05, CE vs. DW. †*p < .05, LT vs. DW.

Averaging just 638 ml in the CE trial, compared with averages of 921 and 915 ml in the LT and DW trials, respectively. While plasma volume was restored with DW, the ingestion of the CE drink significantly expanded the fluid content of the vascular space compared with values seen at rest.

The observation that more of the electrolyte-supplied solution was retained by the subjects in REC than the quantities of LT or DW retained is expected. Gonzalez-Alonso, Heaps, and Coyle (1992) found that a solution containing 6% carbohydrate and 25 mmol/L sodium resulted in better fluid retention than water or a diet soft drink consumed during a 2-hr REC after exercise.

The likely mechanism for the enhanced fluid retention with the CE drinks is greater intestinal water absorption stimulated by the presence of carbohydrate and reduced diuresis by minimizing reductions in plasma osmolality with the sodium content in the drinks. Intestinal water absorption is a passive process dependent on the existence of concentration gradients across the intestinal epithelial cells (Maughan et al., 1996). The active transport of sodium and the associated transport of molecules such as glucose provide such gradients. Therefore, greater fluid retention and lower diuresis were found in the CE trial than the LT and DW trials in this study.

The LT also contains high “sugar” (i.e., carbohydrate), and it is reasonable to assume that the glucose or other carbohydrate present would stimulate water absorption. The poor rehydration produced by the LT is probably the result of a combination of factors. The carbohydrate content of this drink is similar to many other high-sugar soft drinks, which contain 12% carbohydrate and have high osmolalities (>600 mOsmol). Both these factors are likely to reduce gastric emptying, and ingesting such a solution will probably draw water into the intestine rather than encouraging movement across it.

A recent study (Evans, Shirreffs, & Maughan, 2009b) observing the effectiveness of different carbohydrate solutions (0, 2%, 10%) in restoring fluid balance in situations of voluntary fluid intake found that total fluid intake, urine output, net fluid balance, and the fraction of the ingested drink retained were not different among trials. The findings of that study suggested that in situations of voluntary fluid intake, hypertonic CE solutions are as effective as hypotonic CE solutions at restoring whole-body fluid balance in a 2-hr REC (Evans et al., 2009b). Another study from the same research group (Evans, Shirreffs, & Maughan, 2009a) investigated the effects of osmolality (79 ± 4, 193 ± 5, and 667 ± 12 mOsm/kg) and carbohydrate content (0, 2%, and 10%) of drinks with the same sodium concentration (25 mmol/L) on postexercise rehydration. It was found that more of the ingested fluid was retained in the 10% carbohydrate trial (46% ± 9%) than in the 0-carbohydrate trial (27% ± 13%), with 40% ± 4% retained in the 2% carbohydrate trial when the subjects drank a volume that amounted to 150% (range 130–150) of their body-mass loss over a 1-hr REC. Subjects remained euhydrated for 1 hr longer in the 10% glucose trial than in the 2% glucose trial. These studies suggest that if the sodium concentration is comparable, the carbohydrate, in a reasonable range of 2–12%, and osmolality of the ingested solutions did not affect fluid retention when consumed ad libitum (Evans et al. 2009b) but did when drink volumes were prescribed (Evans et al. 2009a), which more closely resembles the current study. Therefore it cannot be concluded that the differences in carbohydrate concentration (CE 6.6% vs. LT 12%) would definitely not affect fluid retention.
Table 2  Abdominal Discomfort (AD) and Stomach Fullness (SF) During Exercise and Recovery in the Carbohydrate-Electrolyte Beverage (CE), Lemon Tea (LT), and Distilled Water (DW) Trials (\(M \pm SD\))

<table>
<thead>
<tr>
<th></th>
<th>Exercise Period (min)</th>
<th>Recovery Period (min)</th>
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<tr>
<td></td>
<td>15  30  45  60</td>
<td>30  60  90  120  150  180  210  240</td>
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<tr>
<td>AD</td>
<td></td>
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<tr>
<td>CE</td>
<td>2.0 ± 0.7 2.0 ± 0.7 2.0 ± 1.0 2.0 ± 0.8</td>
<td>1.4 ± 0.5 1.2 ± 0.5 0.8* ± 0.6 1.1* ± 0.8</td>
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<tr>
<td>LT</td>
<td>1.2 ± 0.8 2.0 ± 0.7 3.1 ± 0.9 2.3 ± 1.1</td>
<td>1.7 ± 1 2.0 ± 1 2.1† ± 1 2.0† ± 1</td>
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<tr>
<td>DW</td>
<td>1.6 ± 1.1 2.1 ± 0.7 2.1 ± 1.1 2.1 ± 0.8</td>
<td>1.5 ± 0.8 1.6 ± 0.9 0.8 ± 0.5 0.7 ± 0.5</td>
</tr>
<tr>
<td>SF</td>
<td></td>
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<tr>
<td>CE</td>
<td></td>
<td>2.3 ± 1.3 2.3 ± 1.0 2.0* ± 1.0 1.8* ± 1.1 1.7* ± 1.2 1.7* ± 1.3 1.5* ± 1.2 1* ± 1.0</td>
</tr>
<tr>
<td>LT</td>
<td></td>
<td>1.9 ± 1.0 2.6† ± 1.1 3.1† ± 1.0 3.4† ± 1.2 4.0† ± 1.2 4.1† ± 1.0 3.4† ± 1.1 3.1† ± 1.1</td>
</tr>
<tr>
<td>DW</td>
<td>2.0 ± 1.0 1.9 ± 1.1 1.9 ± 1.1 2.5 ± 1.2 2.5 ± 1.3 2.4 ± 1.1 2.2 ± 1.3 1.4 ± 1.1</td>
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*\(p < .05\), CE vs. LT. †\(p < .05\), LT vs. DW.
However, the relatively high sodium concentration in the CE in the current study should be the one important element in its effectiveness in restoring hydration status compared with the other two beverages, LT and DW.

Caffeine content in the LT is likely to encourage diuresis despite evidence that hydration is not impaired with habitual ingestion (Davis & Green, 2009; Millard-Stafford et al., 2007; Snell, Ward, Kandawasami, & Stohs, 2010). In Del Coso, Estevez, and Mora-Rodriguez’s report (2009), caffeine (6 mg/kg BM) increased urine flow and sweat electrolyte excretion, but these effects are also not enough to affect hydration or blood electrolyte levels when exercising a long time in a hot environment. It was reported in a recent study that CE drink ingestion with caffeine (195 mg/L) maintains hydration and sustains cardiovascular and thermoregulatory function, as well as CE, during exercise in a warm, humid environment (Millard-Stafford et al., 2007). Thus, it was not surprising that no differences were found in the total urine volume between the LT and the DW in the 4-hr REC in the current study in consideration of its low dosage (70 mg/L or 2 mg/kg BM).

In the current study, the subjects lost ~2.0% of their preexercise BW in all three trials, which was similar to many previous studies (Passe et al., 2004; Wong & Williams, 2000; Wong et al., 2000). The greatest fraction of the retained drink (~52%) was achieved in the CE trial, which also seemed similar to our previous studies that attempted to rehydrate subjects in a short-term 4-hr REC with fluid volumes equivalent to 150% of the fluid lost during an exercise bout (Wong & Williams, 2000; Wong et al., 2000). The amount of fluid (fluid volumes equivalent to 150% of the fluid lost) was chosen to try to rehydrate the subjects and to avoid severe abdominal discomfort (ACSM et al., 2007; Wong & Williams, 2000; Wong et al., 2000). It should be acknowledged that abdominal discomfort was not serious in all the three trials in the current study—only 3 out of 10 on the scale in the highest score of the trials. However, the greater ratings of abdominal discomfort in the LT trial may still indicate that not all the carbohydrate had been absorbed during short-term REC after endurance exercise. Therefore, the perceived benefits of increased carbohydrate intake in the LT may not be realized after acute endurance exercise during the short-term 4-hr recovery period.

In contrast with previous studies, one objective of this study was to observe what occurs in the real world (i.e., the CE solution or the LT being the most popular commercial drink in the Hong Kong market). Thus, the limitation of this particular study is that the energy density, carbohydrate content, caffeine content, and electrolyte composition are not completely comparable in the drinks ingested. The findings of the current study might be the consequence of a number of factors, as mentioned. Although the role of caffeine in the LT might be ignored because of its low dose, it cannot be determined whether the differences in carbohydrate concentration would definitely not affect fluid retention.

In addition, urine volumes were still high at the end of testing, ~400 ml in Hour 4 on each trial, so further ongoing urine losses might not be collected on cessation of the study.

In conclusion, this study is the first conducted in an environment such as Hong Kong to compare the actual rehydration characteristics of a CE solution with other popular drinks such as LT and DW. Consuming the CE drink replaced more fluid lost during a 60-min run and induced a lesser diuretic effect than the other drinks in a 4-hr REC after the run. The CE drink also expanded plasma volume. These results suggest that during a short REC after exercise, a CE solution is a more effective rehydration beverage than other drinks typically consumed in Hong Kong, such as LT and DW. The greater ratings of abdominal discomfort in the current study also suggest that LT might not be a recommended drink during short-term REC after endurance exercise.

References


